PID TUNING OF LINE FOLLOWER ROBOT USING ANDROID SMARTPHONE

Proposed as one or the requirements to complete the degree of Bachelor of Engineering
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by:

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With this acknowledgement I declare that in this final project, by all my knowledge, there is no proposed final project before in same or different university before this journal is being published.

If there is a mistake on my declaration on the future, I will be fully responsible to all my statement.

Surakarta, 31 Desember 2016

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Abstrak

Sebuah kontroler proportional-integral-derivative (PID) adalah sebuah strategi control yang umumnya digunkan pada system otomasi. Sebuah kontroler PID menghitung sebuah nilai kesalahan yang secara kontinyu sebagai perbedaan antara titik yang diinginkan dan hasil pegukuran yang terukur. Pengaturan PID sangatlah krusia pada setiap system yang menggunakan PID. Kesalahan pada pengaturan PID akan mempengaruhi kinerja sebuah robot. Oleh karena itu, pengaturan PID adalah langkah yang penting. Terlebih lagi, kadang-kadang itu sangatlah dibutuhkan untuk mengatur kembali parameter-parameter PID dengan kerusakan minimal pada system. Penelitian ini bertujuan untuk mewujudkan kerusakan minimal itu pada sebuah robot dengan cara pengaturan parameter PID secara nirkabel menggunakan android smartphone melalui bluetooth. Proses pengaturan PID ini dengan cara mengatur nilai proportional, integral dan derivative. Nilai-nilai parameter akan dikirim oleh android smartphone melalui Bluetooth ke system. Robot ini dikontrol oleh arduino UNO yang menerima nilai error dari sensor inframerah. Setelah mendapatkan nilai error, system akan menghitung sinyal control PID.

Kata Kunci: *Android, Arduino, Bluetooth shield, embedded computing.*

Abstract

A proportional-integral-derivative (PID) controller is a control strategy commonly used in automation systems. A PID controller calculates an error value continously as the difference between desired setpoint and measured value. PID tuning is a crucial process that is needed in every system that uses PID. Mistuning of PID parameters greatly affects a robot’s performance. Hence, PID tuning is a very important step. Moreover, sometimes it is desirable to tune the PID parameters with minimal intrusion to the system. This research aims to produce that minimally invasive procedure by tuning the value of PID wirelessly using android phone via bluetooth. The process of tuning PID is adjusting the proportional, integral, and derivative parameter values. The value of these parameters will be sent by an android phone through bluetooth to the robot system. The robot is controlled by Arduino UNO that receives signals from infrared sensors and then computes the error value. After obtaining the error value, the system then calculates the PID control signal.

Keywords: *Android, Arduino, Bluetooth shield, embedded computing.*

1. INTRODUCTION

Smartphones have now become an important part of our life. Primarily used for communication and internet access, smartphones have now found wider use, such as automation. With its features, smartphones --especially Android ones-- become powerful devices that controls electronic devices. Bluetooth and WiFi are two of those features that play role on technology based-on android smartphones.

Line Follower Robot --also called Line Tracer Robot-- is a robot that moves following specifically designed lines. Open-loop control system is a control system that doesn't incorporate feedback. On the other hand, closed-loop control system is a system that takes its output value as a feedback to be proceeded on the next step.

One simple control strategy on many systems is PID based control system. This control system is a mechanism that contains three components: proportional controller(Kp), integral controller(Ki), and derivative controller(Kd). The purpose of most control system on a robot is to make the output and the desired output value (the reference) to be as close as possible. In other words, we want to reduce the errors occuring between them. In this case, we want the line follower robot tracing the lines as close as possible. Here we use closed-loop control strategy, where the output is fedback to the controller.

In PID control system, we need to tune the value of Kp, Ki and Kd to reach the best setting. This process will be hard if we re-program the robot in each tuning process. This is the reason why this research is conducted. In short, our aim is to make android application to adjust the values of Kp, Ki and Kd of the PID controller of the line follower robot.

2. RESEARCH METHODS

This work started in April 2016 as an undergraduate final-year project, and took place at Universitas Muhammadiyah Surakarta. The final product was constructed using the following materials:

- Arduino UNO
- L298N Motor Driver
- 2 DC Motors
- Bluetooth HC-05
- 5 Digital IR Sensors

- 11 Volts Lipo Battery
- Jumper Wires
- A Piece of Wood

In this section we describe the general design of our line-follower robot with its PID controller. Figure 1 describes the general functional block diagram of the robot. The activity of this project starts from putting the robot on the line. After that we let the robot to trace the line. From this point, we see how the robot's performance if it is good or bad in tracing the line. If we are not satisfied with the robot's performance, we can adjust it from our smartphone by changing the Kp, Ki, and Kd values. By clicking on the Kp or Ki or Kd on the smartphone (Figure 6), the robot will stop immediately. After stopping the robot, we are asked to input the new value of Kp or Ki or Kd, depends on what we want. Then the robot will run again with new adjustment.

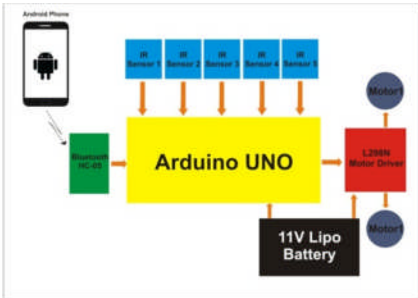


Figure 1. System Block Diagram

Closed-loop control system is used in the line follower robot as shown in Figure 2.

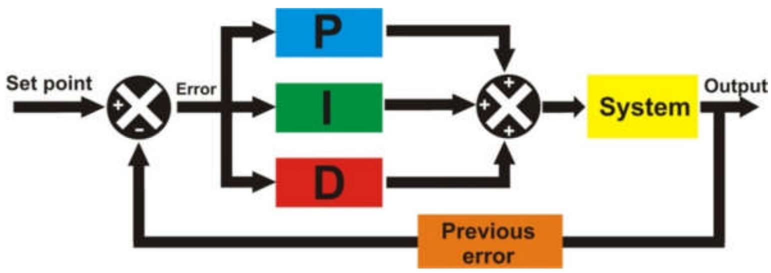


Figure 2. PID Block Diagram

The flowchart of the system is built from a main loop system, and has some subroutines that integrated to the main loop system. The figure 3 below shows the flowchart of the whole system.

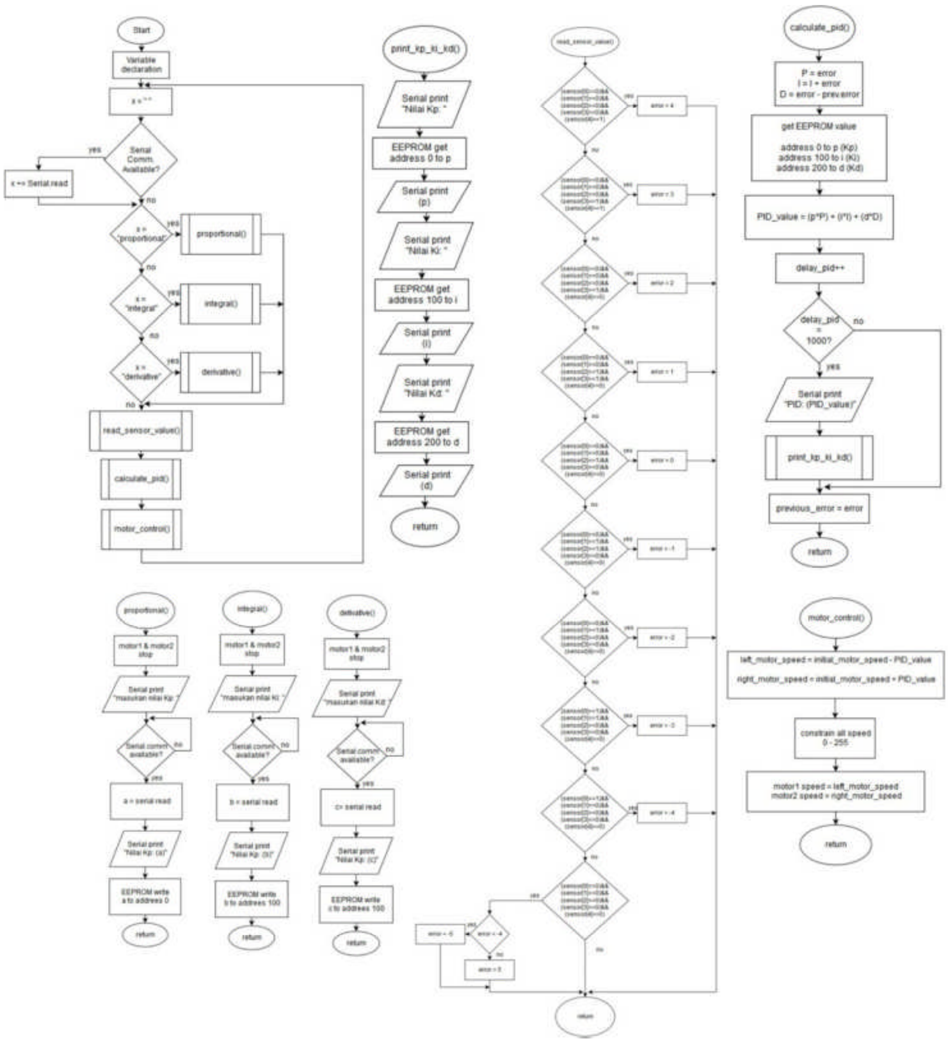


Figure 3. System Flowchart

This system starts from main loop, which has the role as the looping system of whole logic built on the system. The main loop will provide all first setup, all arduino pin initialization, serial communication initialization and all calls to subroutines. This main loop will always loops when the power supply exists on the arduino.

We have several subroutines here, or in a more familiar terms we call it as function. The subroutines built in this system are PID value calculation, motor control, sensor detection, proportional call, integral call, derivative call and PID parameters serial printing subroutine. PID value calculation subroutine is used to calculate the value of PID. Motor control subroutines is functioned as motor controlling system. Sensor subroutine is used to determine the error value in a period of a time, so we can give this error value to PID value subroutine to be calculated as a factor of PID value changing. Proportional call subroutine is used to wait the signal from android smartphone as a call, when it is called, we are asked to input a new Kp value for the system. Integral call subroutine is used to wait the signal from android smartphone as a call, when it is called, we are asked to input a new Ki value for the system. Derivative call subroutine is used to wait the signal from android smartphone as a call, when it is called, we are asked to input a new Kd value for the system. PID parameters serial printing subroutine is used to print the data of PID value and its parameters to the android smartphone as monitoring system.

The whole connection between main loop to the whole system is not only open loop system. This flowchart represents a closed loop control system as we know that there is always a feedback signal occuring to correct the input to the motors. This relation is described in Figure 4 below.

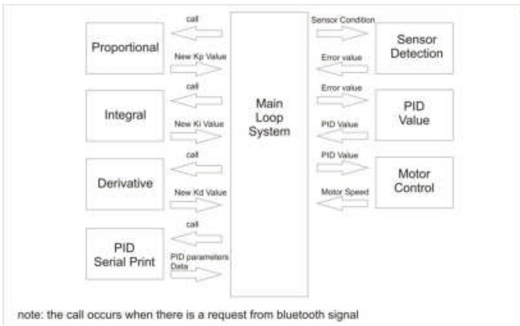


Figure 4. Flowchart Block Diagram

As shown in Figure 4, this robot uses 11 volts battery to power up Arduino and motor driver. Two motors are attached to the Arduino-controlled motor driver. To detect lines, we use 5 digital infrared sensors.

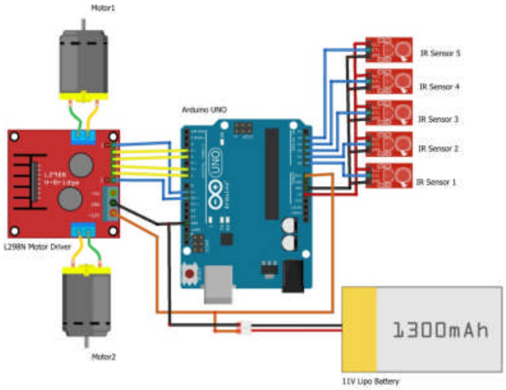


Figure 5. Robot Circuit

The design of android application used in this project is made by using App-Inventor. It contains several buton, a text monitor and a text box.

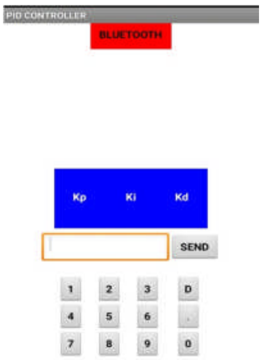


Figure 6. Android Application Design

The logic of our android application also made on App-Inventor. Those all statements are made by doing drag-and-drop activity, as shown in Figure 7 below.

Figure 7. Android Application Logic

3. RESULT AND DISCUSSION

The main idea of this project is how we can easily change PID parameters of a robot using our android smartphone. So Firstly, we need to understand how the line follower robot communicates with the android smartphone. In this project, we use a bluetooth device called HC-05 as a bridge between the robot and the smartphone. By this bluetooth media, we then use serial communication as a mean of communication between the two devices.

The robot works based on arduino that calculates any error occurs. The error is sent from the condition of five infrared sensors to arduino. There error varies from -4 to 4, depends on how the sensors read the line. But the error will become -5 or 5 when the line exceeds from the sensors reach. According to the line that can be detected by the robot, we have nine possibilities of detection, as explained in figure 7 below. And this figure is showing us the front look layout of our sensors location.

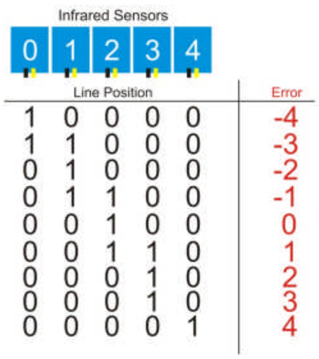


Figure 7. How Sensors Calculate Error

Based on figure 7, our robot movement is decided by the value of error, that is our goal. For instance, our goal when the error is 0, is straight movement. When the error is on negative, the robot should make right turning. The more negative we get, the speed of right turning should be more too. And when it is positive, the goal is left turning. The more positive we get, more speed on left turning too.

When an error produced, arduino determines what PID value is. The formula used in this project is shown in figure 7.

$$PID\_value = (Kp \times P) + (Ki \times I) + (Kd \times D)$$

P = error
I = I + error
D = error - previous_error
Kp = proportional gain
Ki = integral gain
Kd = derivative gain

Figure 8. PID Formula

The PID value in this project is used to control two motors that attached to the robot. After getting PID value, arduino will send certain PWM signal pattern to motor driver (L298N). Then the motor driver amplifies the PWM signal to both motors to control the speed. So, the relationship between PID value and motor speed is shown in figure 8 below.

Left motor speed = initial speed - PID Value
Right motor speed = initial speed + PID Value

initial speed = default speed that set on arduino

Figure 9. PID Value and Motor Speed Relation

Motor speed that produced in this robot is controlled by adjusting the duty cycle. This duty cycle is controlled by arduino based on the calculation above. After getting the value of the right motor and left motor, arduino will send those value to the motor driver to be amplified. We aim to get a proper adjusment for our robot to move following the lines. For a straight movement, the both motors should has same duty cycles. For a right turn, the left motor should be more on duty cycle. Otherwise, a left turn needs more duty cycle on right motor.

3.1 Efficiency Experiment

In this experiment, we will test how the robot will change its performance by varying the Kp, Ki and Kd.

1) Kp Variation

This Kp value will tell us how the robot will respond the line, we will vary the valu of Kp from 0 to its best value that produce its best responsivity to the lines.

Table 1. Kp Variation

Kp	Performance
0	Not responsive
0.5	Not responsive
1	Not responsive
2	Not responsive
10	Not responsive
20	Not responsive
100	Quite responsive
250	Quite responsive
550	Responsive
556	Very responsive
>559	Over responsive

As shown in the table 1 above, we see that Kp value variation cause different responses. When Kp value is 0, it shows that the robot doesn't do anything regarding to line. But when we increase it, we see that the responsivity is changed and finally we find its best responsivity when the value reach 556. And it is over responsive when hit more than 559.

2) Ki Variation

This Ki value variation is actually causing some exponential change on the robot. So, it is shown on table 2.

Table 2. Ki Variation

Ki	Performance
0	Nothing changes
0.01	Uncontrolled movement
0.05	Uncontrolled movement
0.1	Uncontrolled movement
0.2	Uncontrolled movement
0.5	Uncontrolled movement
1	Uncontrolled movement
2	Uncontrolled movement

10	Uncontrolled movement
20	Uncontrolled movement

Exponential change that occurs on a system of this kind of robot is not suitable as shown on table 2. This is because in our robot system, the error will change in linear way. Even it is just small change there, we will realize that giving any value on Ki, will cause any random movement to the robot, except 0. So, the best value of Ki is 0 in this kind of robot.

3) Kd Variation

Kd value variation is conducted to change the performance of the turning of the robot. In this case Kd value in this project will help to increase the speed of the motors when have to turn right of left.

Table 3. Kd Variation

Kd	**Performance**
0	Nothing changes
0.5	Harsh in turning
1	Harsh in turning
2	Harsh in turning
10	Harsh in turning
20	Harsh in turning
40	Harsh in turning
50	Harsh in turning
70	Smooth in turning
90	Smooth in turning
>100	Exceeded Turning

By seeing the table above, we can conclude that giving Kd value will change the performance of turning. But there is a limit when the speed of turning is exceeding, it will make the robot out of reach from the line while turning.

As we can conclude from this experiment, it is decided that Kp=556, Ki=0, Kd=90 is one of the best combination of the line follower robot. The robot performs in its best performance with those values.

3.2 Signal Analysis

Since we have our best combination of Kp, Ki and Kd, we will conduct another experiment to compare some combination to our best combination. In this experiment we will use two errors, 1 and -1. When error is 1 the robot should perform left turning. And when it is -1, the robot should perform right turning. This is explained well if we see figure 6 again, which shows how line detected by the sensors.

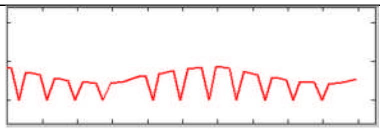
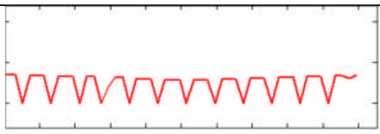
This experiment only comparing the PWM signal duty cycle of the right and left motor visually. So we will leave the calculation behind, and only concern how the pattern of duty cycle of both PWM signal formed.

1) *Left Turn (error=1)*

In this situation of error, the robot should perform left turning. It means that the right motor should have more speed than the left motor.

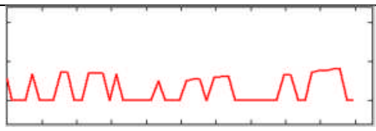
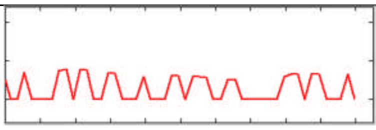
a. *Kp=0, Ki=0, Kd=0*

Table 4. Signal Analysis (a)

Left Motor	Right Motor
	

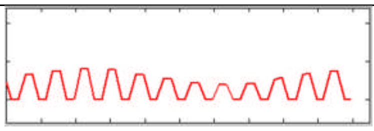
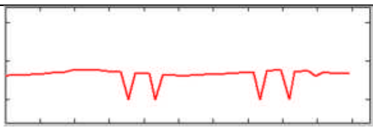
b. *Kp=50, Ki=0.1, Kd=5*

Table 5. Signal Analysis (b)

Left Motor	Right Motor
	

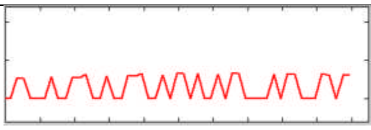
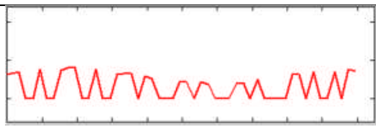
c. *Kp=556, Ki=0, Kd=90*

Table 6. Signal Analysis (c)

Left Motor	Right Motor
	

d. *Kp=700, Ki=1, Kd=200*

Table 7. Signal Analysis (d)

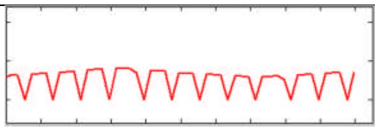
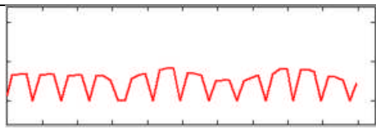
Left Motor	Right Motor
	

2) *Right Turn (error=-1)*

Our goal in this error value, the robot should perform right turning. So, the left motor should have more speed than the right motor.

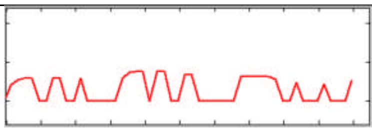
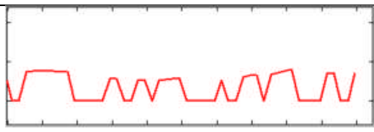
a. *Kp=0, Ki=0, Kd=0*

Table 8. Signal Analysis (e)

Left Motor	Right Motor
	

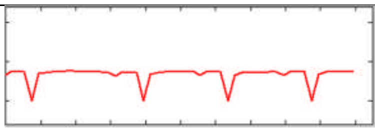
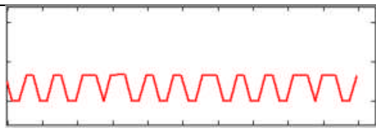
b. *Kp=50, Ki=0.1, Kd=5*

Table 9. Signal Analysis (f)

Left Motor	Right Motor
	

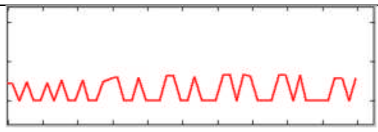
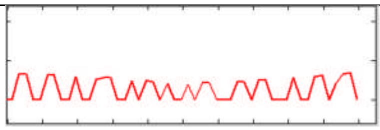
c. *Kp=556, Ki=0, Kd=90*

Table 10. Signal Analysis (g)

Left Motor	Right Motor
	

d. *Kp=700, Ki=1, Kd=200*

Table 11. Signal Analysis (h)

Left Motor	Right Motor
	

From this experiment, we see that only when Kp = 556, Ki = 0 and Kd = 90, the motor performance is in its best. The duty cycle occurs while turning on both motor indicates a good combination. When right turning, the duty cycle on left motor should be higher. Also when left turning, right motor duty cycle should be higher too.

Another combinations that we use in this experiment show that the duty cycles of both motors are randomly formed. This is why in those combinations, the robot randomly changes its both motors speed.

3.3 Communication Range

In this experiment, we will test the communication range between the robot and the android smartphone. Bluetooth signal is used in this project to be a medium signal of the data transfered from the robot to the android smartphone and vise versa. For sure, to communicate wirelessly trough bluetooth, there is a range limit of the matter of distance. General bluetooth device on market, usually has range until around 10 meters. But, we need to prove it if it is true fact or not. In this project we use two bluetooth, HC-05 Bluetooth for the robot and android smartphone bluetooth.

Table 11. Bluetooth Test

No.	Distance	Connection	Transfered Data
1	1 Meters	Connected	Fast
2	3 Meters	Connected	Fast
3	5 Meters	Connected	Fast
4	8 Meters	Connected	Fast
5	10 Meters	Connected	Fast
6	12 Meters	Connected	Fast
7	13 Meters	Connected	Delayed
8	15 Meters	Not connected	Not Transfered

By conducting this experiment, we can prove that the distance between the robot and the android smartphone is a real matter. Because it will delay the data transfer. By this fact, we need to be close enough to the robot if we want to have a good data transfer. Last, if the distance more than 13 meters, the connection will be lost.

3.4 Analysis

From the first experiment that we did, we can analyze that the robot performance depends on Kp, Ki and Kd combination. Kp value affects the responsivity of the robot towards the line. Ki value affects the movement of the robot exponentially. Because we use the type of robot that has small incremental linear error values, we leave it 0. Kd value affects the turning performance, in other words, it changes the speed of the motor while turning.

Duty cycle in a DC motor control is a crucial thing, we can adjust the duty cycle when we want to increase the speed of the motor by increasing it. And we can decrease the speed of the motor by decreasing it. So by this logic, a robot can turn right when the left motor is in higher duty cycle. Also when the robot make a left turn, so the duty cycle on right motor should be higher. In the second experiment, we can see what Kp, Ki and Kd affect to the duty cycles of both motors.

4. CONCLUSION

If we see how big the number of possibility of the combination of Kp, Ki and Kd to determine the best PID value of a system, it is very hard to do it by reprogramming the robot trough a computer. This way of PID tuning will make all the robot makers very happy, because they don’t need to bring their laptop or even big personal computer. Only bringing their robot and a piece of smartphone on pocket while performing the robot is the best preference.

Building android application with advance programming is a good way. But, for some engineers, to program an android application is not that easy. MIT (Massachusetts Institute of Technology) provide us a simple way to build an android application by their software called App Inventor. For building an android application based on electronics, they provide us some features that can support our electronic project. That is way, the writer suggest all electronic engineers who don’t have any experience in mobile application programming to use it as a tool.

Considering the type of wireless technology to control a system is a need. For this project for instance, our distance of controlling the robot is not more than 10 meters.

But, if we design it to control in more distances, we really need to change the medium using high-level of wireless technology.

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